Effects of Weeds on Selected Arthropod Herbivore and Natural Enemy Populations, and on Cotton Growth and Yield

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ABSTRACT Vegetative diversification with weeds can enhance natural enemy populations and suppress pest-related damage in various crops. Weedy and weed-free cotton (*Gossypium hirsutum* L.) plots were used to study the effects of weediness on selected herbivorous arthropod groups, including the boll weevil (*Anthonomus grandis grandis* Boheman), and natural enemies, boll weevil-induced injury to cotton squares, and cotton plant growth and yield in the Lower Rio Grande Valley of Texas, during 2000 and 2001. The presence of weeds was associated with greater populations of 9 of the 11 prey arthropod groups, and 9 of the 13 natural enemy arthropod groups counted in this study. These trends were mostly evident late in the season when weed biomass was greatest. Weed-free cotton harbored more cotton aphids (*Aphis gossypii* Glover), early in the season and silverleaf whiteflies (*Bemisia argentifolii* Bellows and Perring) later in the season than weedy cotton on some of the sampling dates. Diversity (Shannon's index) within the selected arthropod groups counted in this study was significantly greater in dvac samples from the weed foliage than from weed-free cotton plants during both years, and diversity on weedy cotton plants was greater than on weed-free cotton plants during 2000. Boll weevil oviposition injury to squares was unaffected by weeds, but the higher weed-associated predator populations mainly occurred after most squares had become less vulnerable bolls. Weed competition resulted in lower lint yields of 89% and 32% in the 2 yr.

KEY WORDS *Anthonomus grandis*, boll weevil, cotton, natural enemies, vegetative diversity, weeds

Vegetative diversification in some crop systems can enhance natural enemy populations and suppress pest related damage in various crops, potentially reducing the need for costly and ecologically disruptive insecticide applications (Altieri et al. 1977, Showler and Reagan 1991). Theories that explain the lower pest infestations in many vegetatively diversified cropping systems include: (1) spatial dilution of the primary resource (Bach 1980, Risch 1981), (2) chemical or structural interference with host location and use by herbivores (Atsatt and O'Dowd 1976, Nordland et al. 1984), and (3) enhanced natural enemy populations (Barney et al. 1984, Foster and Ruesink 1984).

In cotton (*Gossypium hirsutum* L.), vegetative diversification in the form of strip cropping with alfalfa (*Medicago sativa* L.) concentrates lygus bug (*Lygus hesperis* Knight) populations and acts as a reservoir for beneficial insects (Stern et al. 1969, Godfrey and Leigh 1994). The trap crops safflower (*Carthamus tinctorius* L.), kenaf (*Hibiscus cannabinus* L.), and redroot pigweed (*Amaranthus retroflexus* L.) (Stewart and Layton 2000), also divert *Lygus* spp. away from cotton. Populations of *Chrysoperla* spp. lacewing adults increased in cotton when strip cropped with sorghum (*Sorghum halpense* L.), corn (*Zea mays* L.), or alfalfa (Smith and Reynolds 1972, Massey and Young 1975). Montandon and Slosser (1996) demonstrated that canola (*Brassica napus* L.) and wheat (*Triticum aestivum* L.) in the winter "relayed" aphid predators to sorghum in the spring, and from sorghum to cotton in the summer.

Vegetative diversification with weeds can improve some crop yields by suppressing damage by key pests (Altieri and Whitcomb 1980, Showler and Reagan 1991). In Louisiana sugarcane (*Saccharum officinarum* L.), imported fire ants (*Solenopsis invicta* Buren), other formicid species, araneaeids (spiders), carabids, dermapterans, and staphylinids were more abundant in weedy sugarcane (Adams et al. 1981, Ali and Reagan 1986, Showler et al. 1989), and sugarcane borer (*Diatraea saccharalis* F.), injury to sugarcane was significantly reduced (Showler and Reagan 1991). Schultz (1988) found fewer chrysopid eggs on cotton plants intercropped with corn and weeds than in cotton monocultures, probably because of earwig predation on chrysopid eggs. Although the effects of weeds on prey and natural enemy arthropod populations, including key pests, in agroecosystems have not been established, cotton growth and yields are known to be adversely affected by competitive weed growth (Snipes et al. 1982, Rowland et al. 1999).

This study was conducted to evaluate the effects of indigenous weed growth on selected herbivorous prey and natural enemy arthropod populations, and on cotton growth and yield in the Lower Rio Grande Valley of Texas. Also, the efficiency of natural enemy populations in the Lower Rio Grande Valley, if enhanced by weed growth, can be assessed in terms of their collective impact on damage caused by boll weevils and other important herbivores, including cotton aphids and silverleaf whiteflies.

Materials and Methods

A 0.8-ha field at the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center (USDA-ARS SARC) in Hidalgo Co., TX, was planted to cotton (variety. Deltapine-50RR) on 6 March 2000. Another 0.8-ha field 3 km away, also at the USDA-ARS SARC, was planted to the same variety of cotton on 12 March 2001. Six plots, each 12 rows wide (row width $\approx$ 1.0 m) by 53.5 m long, were weedy, and six plots of equal dimensions were weed-free, arranged in a completely randomized design during each year. Weed-free plots received a postplant application of the herbicide pendimethalin (924 g a.i./ha), and at the 4-leaf stage of cotton development, weeds emerging in the furrows were removed with a rolling cultivator. In addition, weeds on the rows were manually removed on a weekly basis and spot treated with glyphosate 2 wk after planting. Weeds were not managed in the weedy plots.

On 18 April, 1 June, and 7 July 2000, and on 2 May, 6 June, and 9 July 2001, all weeds in two randomly thrown 0.5-m^2 quadrats per weedy plot were clipped at the soil surface. The weed species were partitioned in separate paper bags, oven dried for 48 h at 60°C, and weighed. Soil surface-associated arthropods were sampled using two pitfall traps (Greenslade 1964) per plot, changed once every 2 wk from 18 April to 27 June 2000, and from 16 April to 25 June 2001 (five times in each year). Arthropods in the groups listed in Tables 1 and 2 were counted in 70% isopropyl alcohol after the jars' contents were emptied into counting trays. A dvac suction machine (Dvac Company, Ventura, CA) was used to collect arthropods from cotton in all plots, and weed foliage in the weedy plots by placing a 33-cm diameter nozzle directly on the cotton plots or weed foliage between the cotton rows for 5 s at five random locations in the center four rows of each plot. Dvac sampling was conducted once every 2 wk from 2 May to 27 June 2000, and from 23 April to 18 June 2001 (five times in each year). Dvac collection bags were emptied into jars with 70% isopropyl alcohol and stored until the contents were poured into trays, classified into groups as listed in Tables 3 and 4, and counted. Tropical fire ant (*Solenopsis geminata* F.) colonies were counted on 3 and 9 July in 2000 and 2001, respectively.

Table 1. Comparison of populations of selected herbivorous arthropods collected in pitfall jars in weedy and weed-free cotton plots, Hidalgo County, TX, 2000 and 2001, using repeated measures analyses

Effect[a]	Year	Arthropod group[b]	F	df	P
Treatment	2000	Cicadellidae	167.15	1, 50	<0.0001
		Coleoptera[c]	6.10		0.017
		Diptera[d]	113.79		<0.0001
		Hemiptera[e]	22.37		<0.0001
		Lepidoptera larvae	51.40		<0.0001
		Orthoptera[f]	17.68		0.0001
	2001	Lepioptera larvae	6.75		0.0123
Time	2000	Cicadellidae	4.03	4, 50	0.0065
		Diptera[d]	52.41		<0.0001
		Hemiptera[e]	4.71		0.0027
		Lepidoptera larvae	9.31		<0.0001
		Orthoptera[f]	5.07		0.0016
	2001	Cicadellidae	17.94		<0.0001
		Coleoptera[c]	8.58		<0.0001
		Diptera[d]	24.99		<0.0001
		Hemiptera[e]	6.20		0.0004
		Lepidoptera larvae	5.17		0.0015
Interaction	2000	Diptera[d]	11.96	4, 50	<0.0001

[a] Treatment, weedy and weed-free cotton plots; time, pitfall jars were set out from 18 March to 27 June 2000 and from 16 April to June 2001, collected at 2-wk intervals; interaction, treatment*time.

[b] Only arthropod groups with significant ($P \leq 0.05$) effects or interactions are presented.

[c] Mostly Anthicidae, Chrysomelidae, Elateridae, and Tenebrionidae.

[d] Mostly Agromyzidae, Calliphoridae, Cecidomyiidae, Ceratopogonidae, Chironomidae, Dolichopodidae, Drosophilidae, Muscidae, and Sarcophagidae.

[e] Mostly Largidae, Lygaeidae, Miridae, and Pentatomidae.

[f] Mostly Acrididae, Gryllidae, and Blattidae.

Table 2. Comparison of populations of selected arthropod natural enemies collected in pitfall jars in weedy and weed-free cotton plots, Hidalgo County, TX, 2000 and 2001, using repeated measures analyses

Effect[a]	Year	Arthropod group[b]	F	df	P
Treatment	2000	Carabidae	11.28	1, 50	0.0015
		Dermaptera	27.48		<0.0001
		Geocoris spp.[c]	14.40		0.0004
	2001	Dermaptera	16.49		<0.0001
Time	2000	Coccinellidae	11.36	4, 50	<0.0001
		Dermaptera	3.14		0.0473
		Orius spp.[d]	13.57		<0.0001
		Staphylinidae	22.18		<0.0001
		Wasps[e]	4.41		0.0039
		Spiders[f]	34.39		<0.0001
	2001	Formicidae[g]	6.59		0.0002
		Coccinellidae	217.81		<0.0001
		Collops[h]	3.28		0.0182
		Dermaptera	16.49		<0.0001
		Geocoris spp.[c]	9.50		<0.0001
		Neuroptera[i]	16.17		<0.0001
		Orius spp.[d]	2.82		0.0349
		Staphylinidae	16.84		<0.0001
		Wasps[e]	8.46		<0.0001
Interaction	2000	Carabidae	2.71	4, 50	0.0343
		Coccinellidae	6.47		0.0003
		Geocoris spp.[c]	5.81		0.0006

[a] Treatment, weedy and weed-free cotton plots; time, pitfall jars were set out from 18 March to 27 June 2000 and from 16 April to June 2001, collected at 2-wk intervals; interaction, treatment*time.

[b] Only arthropod groups with significant ($P \leq 0.05$) effects or interactions are presented.

[c] Family Lygaeidae.

[d] Family Anthocoridae.

[e] Mostly Braconidae, Eupelmidae, Eurytomidae, Ichneumonidae, Pteromalidae, Sphecidae, and Trichogrammatidae.

[f] Mostly Clubionidae, Linyphiidae, Lycosidae, Salticidae, and Thomisidae.

[g] Mostly *Atta* spp. and *Solenopsis geminata*.

[h] Family Melyridae.

[i] Families Chrysopidae, and Hemerobiidae.

Table 3. Comparisons, using repeated measures analyses, of populations of selected herbivorous arthropods collected by dvac from cotton plants in weedy and weed-free plots, and from the weed foliage in weedy plots, Hidalgo County, TX, 2000 and 2001, using repeated measures analyses

Effect[a]	Year	Arthropod group[b]	*F*	df	*P*
Treatment	2000	Aphididae	6.23	2,75	0.0031
		Aleyrodidae	11.47		<0.0001
		Cicadellidae	105.07		<0.0001
		Coleoptera[c]	21.14		<0.0001
		Diptera[d]	37.01		<0.0001
		Hemiptera[e]	53.50		<0.0001
		Lepidoptera larvae	5.79		0.0005
		Thripidae	25.84		<0.0001
	2001	Aphididae	10.67		<0.0001
		Aleyrodidae	20.65		<0.0001
		Cicadellidae	49.43		<0.0001
		Coleoptera[c]	11.41		<0.0001
		Diptera[d]	17.79		<0.0001
		Hemiptera[e]	12.09		<0.0001
		Thripidae	12.41		<0.0001
Time	2000	Aphididae	70.22	4,75	<0.0001
		Aleyrodidae	5.98		0.0003
		Cicadellidae	49.39		<0.0001
		Coleoptera[c]	21.20		<0.0001
		Diptera[d]	63.01		<0.0001
		Hemiptera[e]	50.78		<0.0001
		Lepidoptera adults[f]	65.83		<0.0001
		Thripidae	29.74		<0.0001
	2001	Aphididae	104.71		<0.0001
		Aleyrodidae	29.76		<0.0001
		Cicadellidae	9.01		<0.0001
		Coleoptera[c]	29.31		<0.0001
		Diptera[d]	42.33		<0.0001
		Hemiptera[e]	19.53		<0.0001
		Thripidae	19.12		<0.0001
Interaction	2000	Aleyrodidae	2.90	8,75	0.0071
		Coleoptera[c]	3.11		0.0044
		Lepidoptera adults[f]	6.95		<0.0001
		Lepidoptera larvae	3.80		0.0009
		Thrips	4.90		0.0001
	2001	Aphididae	4.40		0.0002
		Aleyrodidae	2.90		0.0071

[a] Treatment, weedy and weed-free cotton plots; time, dvac samples (five suctions per sample) were taken at 2-wk intervals from 18 March to 27 June 2000 and from 16 April to June 2001, interaction, treatment*time.
[b] Only arthropod groups with significant ($P \leq 0.05$) effects or interactions
[c] Mostly Anthicidae, Chrysomelidae, and Elateridae (boll weevils not found in dvac collections).
[d] Mostly Agromyzidae, Calliphoridae, Cecidomyiidae, Chironomidae, Dolichopodidae, Drosophilidae, and Muscidae.
[f] Mostly Geometridae, Noctuidae, and Pyralidae.

Table 4. Comparisons, using repeated measures analyses, of populations of selected arthropod natural enemies collected by dvac from cotton plants in weedy and weed-free plots, and from the weed foliage in weedy plots, Hidalgo County, TX, 2000 and 2001, using repeated measures analyses

Effect[a]	Year	Arthropod group[b]	*F*	df	*P*
Treatment	2000	Formicidae[c]	4.39	2,75	0.0158
		Geocoris spp.[d]	31.51		<0.0001
		Nabis spp.[e]	17.80		<0.0001
		Orius spp.[f]	55.64		<0.0001
		Neuroptera[g]	5.13		0.0082
		Spiders[h]	5.08		0.0007
	2001	Formicidae[c]	4.95		0.0085
		Coccinellidae	7.21		0.0014
		Nabis spp.[e]	7.18		0.0014
		Orius spp[f]	20.67		<0.0001
		Wasps[i]	53.63		<0.0001
Time	2000	*Geocoris* spp.[d]	34.21	4,75	<0.0001
		Nabis spp.[e]	18.31		<0.0001
		Orius spp.[f]	65.76		<0.0001
		Reduviidae	4.11		0.0046
		Wasps[i]	53.63		<0.0001
		Spiders[h]	19.74		<0.0001
	2001	Coccinellidae	11.00		<0.0001
		Nabis spp.[e]	11.26		<0.0001
		Orius spp.[f]	45.53		<0.0001
		Wasps[i]	35.51		<0.0001
		Spiders[h]	26.34		<0.0001
Interaction	2000	*Geocoris* spp.[d]	2.71	8,75	0.0113
		Nabis spp.[e]	3.04		0.0051
		Orius spp.[f]	3.57		0.0032
		Reduviidae	2.28		0.0306
	2001	*Nabis* spp.[e]	3.17		0.0038

[a] Treatment, weedy and weed-free cotton plots; time, dvac samples (five suctions per sample) were taken at 2-wk intervals from 18 March to 27 June 2000 and from 16 April to June 2001, interaction, treatment*time.
[b] Only arthropod groups with significant ($P \leq 0.05$) effects or interactions are presented.
[c] Mostly *Atta* spp. and *Solenopsis geminata.*
[d] Family Lygaeidae.
[e] Family Nabidae.
[f] Family Anthocoridae.
[g] Chysopidae and Hemerobiidae.
[h] Mostly Linyphiidae, Salticidae, and Thomisidae.
[i] Mostly Braconidae, Eulophidae, Eupelmidae, Ichneumonidae, Pteromalidae, Sphecidae, and Trichogrammatidae.

Boll weevil (*Anthonomus grandis grandis* Boheman) damage was determined by examining 50 randomly selected squares per plot on 22 and 30 May during 2000 and 2001. To examine predation against the boll weevil, five cotton squares (4–9-mm diameter) infested with eggs and larvae of boll weevils were tied to a 1-m length of string at 25-cm intervals. Two strings of cotton squares were laid across furrows (one end of the string was under the canopy of one row, and the other end was under the cotton canopy of the adjacent row) at random locations in each plot for 7 d, then the strings were replaced by new strings of infested squares and the old strings were taken to the laboratory for dissection. Mortality factors were visually determined (Sturm and Sterling 1986). This procedure was repeated for 9 wk between 16 May and 12 July.

Numbers of cotton plants in two 4-m sections of row in each plot were counted on 20 April and 5 July 2000, and on 26 April and 11 July 2001. Numbers of squares and bolls on cotton plants in a 7.6-m section of row in each plot were counted on 1 May and 19 June, respectively, in 2000, and on 8 May and 27 June, respectively, 2001. On 15 and 29 May 2000 and 2001, respectively, heights of 25 randomly selected cotton plants in each plot were measured. Plots were defoliated on 7 July 2000 and 11 July 2001 with DEF (S, S, S-tributylphosphorotrithioate) at a rate of 1,681.3 g a.i./ha. Cotton was hand harvested from two 4-m lengths of row in each plot on 14 July 2000 and 23 July 2001, and within 3 d the cotton was ginned and the lint was weighed.

Changes in weed biomass were evaluated using one way analysis of variance (ANOVA), for each year.

One-way analysis of variance was also used to assess the effects of weed treatments on boll weevil mortality and injury to cotton squares, and cotton growth and yield measurements for each year. Repeated measures analyses (Analytical Software 1998) were run to assess the effects of treatment and time on the numbers of insects collected in the pitfall traps and by the dvac. Insect numbers were $\log(x + 1)$-transformed before repeated measures analyses; however, untransformed means are presented. Pearson correlations were run on numbers of total prey and total natural enemies collected in pitfall traps and in dvac samples (Analytical Software 1998). Shannon's diversity indices (Price 1975) were calculated separately for pitfall and dvac collected arthropods in selected categories for each date and one-way analysis of variance was used to assess treatment differences between diversity indices for each year (Zar 1999).

Results

Weed Biomass. Weed species in the 2000 plots consisted of pigweed (*Amaranthus* spp.), common ragweed (*Ambrosia artemisiifolia* L.), ground cherry (*Physalis heterophylla* Nees von Esenbeck), spurge (*Euphorbia* sp.), and Texas panicum, (*Urochloa texana* Buckley), R.D. Webster (Table 5). In 2001, weed species encountered were pigweed, woolly croton (*Croton capitatus* Michaux), common purslane (*Portulaca oleracea* L.), cowpen daisy (*Verbesina encelioides* Cavanilles) G. Bentham & J. Hooker *ex.* A. Gray, nutgrass (*Cyperus rotundus* L.), and Texas panicum.

In 2000, dry weed biomass in the weedy plots increased from 19 April to 1 June by 4.3-fold, and from 19 April to 7 July by 5.6-fold ($F = 19.8$; df = 2, 10; $P = 0.0001$), and in 2001 dry weed biomass increased from 2 May to 6 June by 1.3-fold, and from 2 May to 9 July by 2.9-fold ($F = 4.41$; df = 2, 10; $P = 0.0439$). The dry weed biomass was consistently higher during 2000 than during 2001 (Table 5). During 2000, the biomass of dicot weeds ranged from 38% to 51%, and during 2001 ranged from 18% to 69%.

Table 5. Mean weed dry biomass (g/0.5 m^2 ± SE) in weedy cotton plots, Hidalgo County, TX, 2000 and 2001

Species	Sampling		
	2000		
	18 April	1 June	7 July
Pigweed	8.9 ± 2.1b	38.5 ± 10.2a	35.5 ± 8.6ab
Common ragweed	0.3 ± 0.1b	13.1 ± 3.3a	13.8 ± 4.3a
Ground cherry	0.2 ± 0.2	1.8 ± 1.1	2.1 ± 1.2
Spurge	0.1 ± 0.02	0.4 ± 0.4	1.2 ± 0.7
Texas panicum	15.4 ± 5.9c	52.4 ± 6.1b	86.9 ± 5.4a
Total weeds	24.8 ± 5.6b	106.2 ± 17.0a	139.5 ± 15.0a
	2001		
	2 May	6 June	9 July
Pigweed	2.5 ± 2.5	0.9 ± 0.9	2.6 ± 2.3
Common purslane	0	0.1 ± 0.1	0.9 ± 0.5
Woolly croton	1.5 ± 1.5	1.5 ± 1.5	2.6 ± 2.5
Golden crownbeards	6.0 ± 3.0	6.4 ± 4.3	1.3 ± 1.3
Nutgrass	0.7 ± 0.4	1.6 ± 0.9	3.8 ± 2.4
Texas panicum	3.6 ± 2.2	8.9 ± 4.8	30.9 ± 16.9
Total weeds	4.5 ± 3.6b	19.5 ± 2.9b	42.2 ± 5.5a

Means followed by different letters within the same row are significantly different ($P \leq 0.05$); means not followed by letters are not significantly different; $n = 6$ per sampling date.

Table 6. Shannon's diversity indices for selected arthropod groups collect in pitfall traps and by dvac machine in weedy (W) and weed--free (WF) cotton habitats, Hidalgo County, TX, 2000 and 2001

Sampling method	Year	Habitat	Diversity index	F[a]	P
Pitfall[b]	2000	W	0.914 ± 0.028	1.62	0.238
		WF	0.854 ± 0.088		
	2001	W	0.865 ± 0.046	0	0.952
		WF	0.861 ± 0.044		
Dvac[c]	2000	WC	0.784 ± 0.031a	12.47	0.001
		WW	0.834 ± 0.007a		
		WFC	0.569 ± 0.061b		
	2001	WC	0.601 ± 0.065ab	4.17	0.042
		WW	0.789 ± 0.049a		
		WFC	0.561 ± 0.0636b		

Means followed by different letters within each year are significantly different ($P \leq 0.05$). W, weedy; WF, weed-free; WC, weedy cotton plants; WW, weed foliage; WFC, weed-free cotton plants.

[a] One-way ANOVA; pitfall data df = 1, 8; dvac data df = 2, 12.

[b] Two pitfall traps per plot, $n = 6$; collected every 2 wk, 2 May to 27 June 2000, and from 30 April to 25 June 2001 (five times each year).

[c] Five dvac suction from each plot, $n = 6$; collected every 2 wk, 2 May to 27 June 2000, and from 23 April to 18 June (five times each year).

Pitfall-Collected Arthropods. No significant treatment differences in Shannon's diversity indices were detected in either year (Table 6). Herbivorous arthropods counted in the pitfall jars during 2000 and 2001 were in orders Homoptera, Hemiptera, Coleoptera, Diptera, Lepidoptera, and Orthoptera.

Repeated measures analyses revealed that the weedy treatment had significant effects on the numbers of cicadellids, herbivorous hemipterans and coleopterans, dipterans, lepidopteran larvae, and orthopterans in 2000 (Table 1). In 2001, there was a treatment effect on the numbers of lepidopteran larvae (Table 1). The effect of time was significant on the numbers of cicadellids, herbivorous hemipterans, dipterans, lepidopteran larvae, and orthopterans in 2000, and on the numbers of cicadellids, herbivorous hemipterans and coleopterans, dipterans, and lepidopteran larvae (Table 1). An interaction was detected between treatment and time for numbers of dipterans during 2000 (Table 1).

During 2000, numbers of cicadellids (Fig. 1A), herbivorous hemipterans (Fig. 1B) and coleopterans (Fig. 1C), dipterans (Fig. 1D), lepidopterous larvae (Fig. 1E), and orthopterans (Fig. 1F) were greater in the weedy treatment on most of the sampling dates than in the weed-free treatment on most of the sampling dates. Numbers of herbivorous hemipterans (Fig. 1B) and coleopterans (Fig. 1C), and lepidopterous larvae (Fig. 1E) were greater on one or two sampling dates during 2001.

Predatory and parasitic arthropods (henceforth referred to as natural enemies) counted in the pitfall jars during 2000 and 2001 were in orders Hemiptera, Coleoptera, Dermaptera, Hymenoptera, and Neurop-

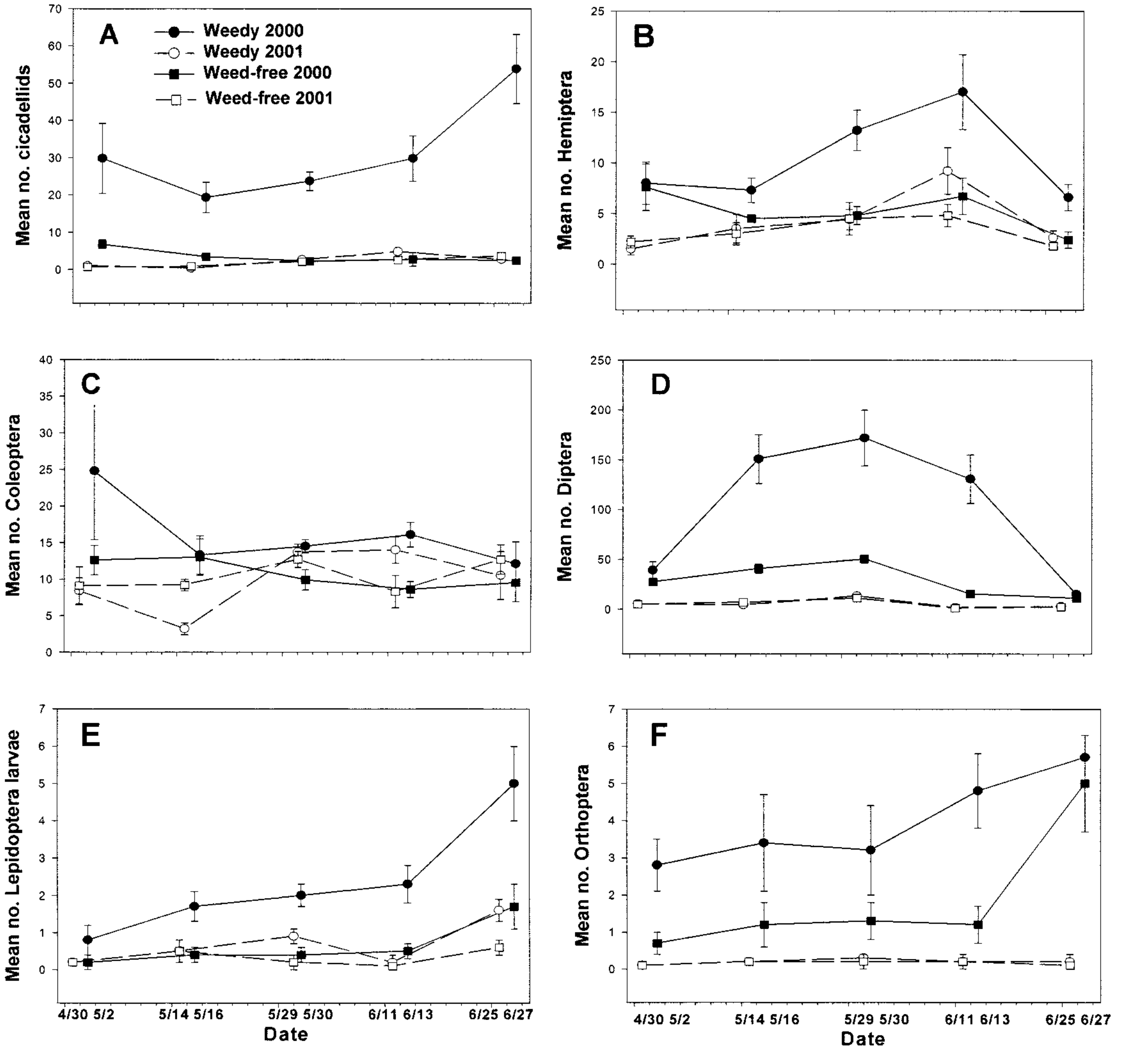

Fig. 1. (A–F) Mean (±SE) numbers of selected prey arthropod groups collected in pitfall traps in weedy and weed-free cotton plots, Hidalgo Co., TX.

tera, and order Araneae in the class Arachnida. Repeated measures analyses showed that the treatment had significant effects on the numbers of *Geocoris* spp., carabids, and dermapterans in 2000, and on the numbers of dermapterans in 2001 (Table 2). Time effects were significant on numbers of *Orius* spp., coccinellids, staphylinids, demapterans, wasps, and spiders in 2000, and during 2001 on the numbers of *Geocoris* spp., *Orius* spp., coccinellids, *Collops* spp., staphylinids, dermapterans, neuropterans, formicids, and wasps (Table 2). Significant interactions were detected between treatment and time effects for numbers of *Geocoris* spp., carabids, and coccinellids in 2000, although no interactions were detected during 2001.

Geocoris spp. (Fig. 2A), *Orius* spp. (Fig. 2B), carabids (Fig. 2C), staphylinid (Fig. 2E) dermapterans (Fig. 2 F), wasps (Fig. 2H), and spiders (Fig. 2I) were most numerous in the weedy treatment on one or two of the sampling dates in 2000 and, to less pronounced degrees, in 2001. Dermapterans were more most abundant in the weed-free treatment on the middle sampling date in 2000. On the middle and second sampling dates of 2000, pitfall-collected coccinellid (Fig. 2D) and formicid (Fig. 2G) populations, respectively, were higher in the weed-free treatment than in the weedy treatment.

Dvac-Collected Arthropods. Shannon's diversity indices were significantly greater in samples collected from weedy cotton plants and from weed foliage than from weed-free cotton plants during 2000, and from weed foliage than from weed-free cotton plants during 2001 (Table 6). Herbivorous arthropod groups that were counted in the dvac samples belong to orders Coleoptera, Diptera, Hemiptera, Homoptera, Lepidoptera, and Thysanoptera. Repeated measures analyses revealed that the weed treatment had significant effects on the numbers of cotton aphids (*Aphis gossypii* Glover), silverleaf whiteflies (*Bemisia argentifolii*

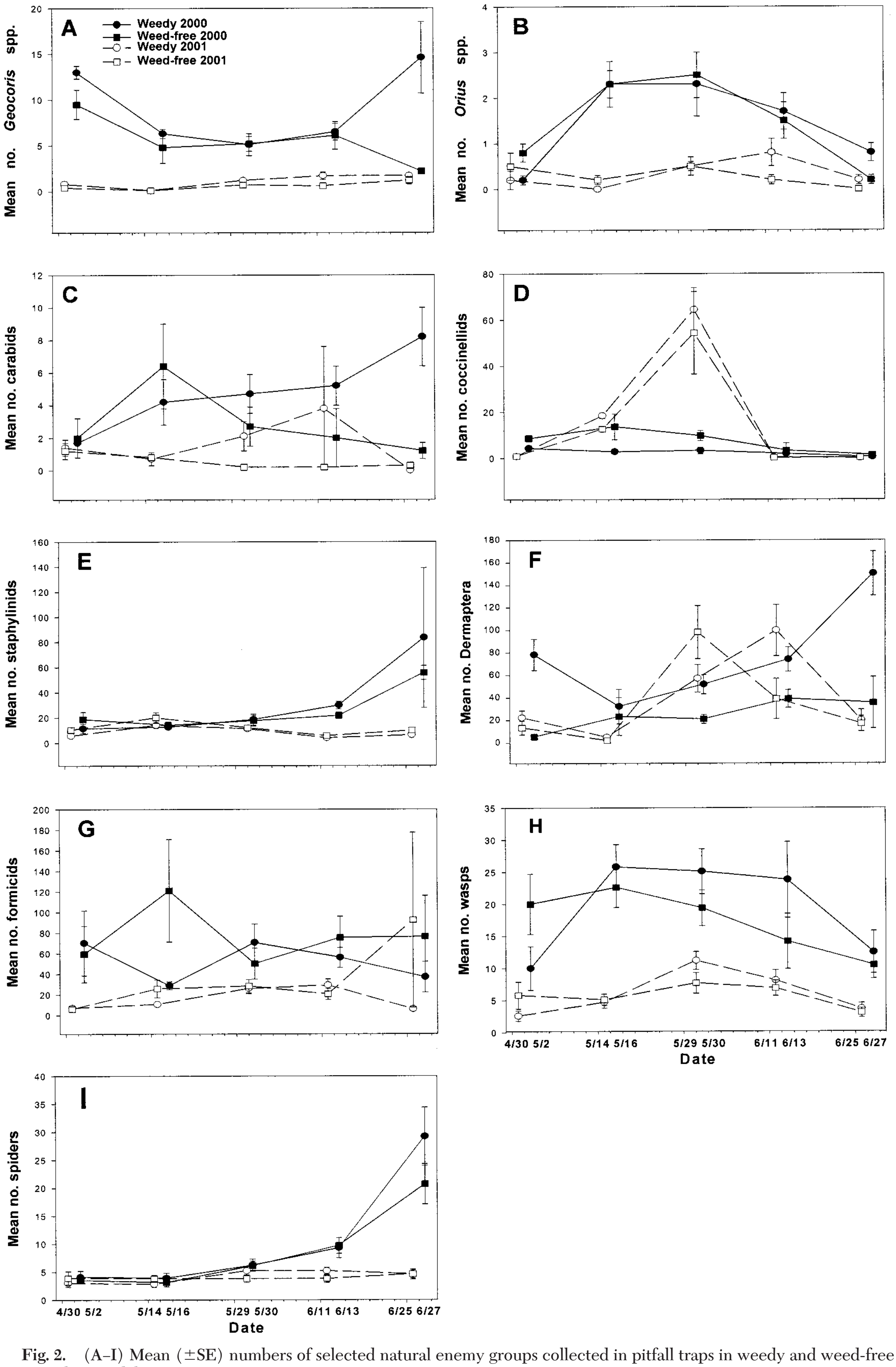

Fig. 2. (A–I) Mean (±SE) numbers of selected natural enemy groups collected in pitfall traps in weedy and weed-free cotton plots, Hidalgo Co., TX.

Bellows and Perring), cicadellids, herbivorous hemipterans and coleopterans, dipterans, thrips, and lepidopteran larvae in 2000; and on the numbers of aphids, whiteflies, cicadellids, herbivorous hemipterans and coleopterans, dipterans, and thrips during 2001 (Table 3). The effects of time were significant on the numbers of aphids, whiteflies, cicadellids, herbivorous hemipterans and coleopterans, dipterans, thrips, and lepidopteran adults and larvae in 2000 (Table 3). During 2001, the effects of time were significant on numbers of aphids, whiteflies, cicadellids, herbivorous hemipterans and coleopterans, dipterans, and thrips (Table 3). Significant interactions were detected between treatment and time effects for numbers of whiteflies, herbivorous coleopterans thrips, and lepidopteran adults and larvae in 2000, and for numbers of aphids and whiteflies in 2001 (Table 3).

Abundances of aphids (Fig. 3A) and whiteflies (Fig. 2B) appeared to be greater on the weed-free cotton plants than on weedy cotton plants and/or weed foliage in late April or early May, and in the latter half of June, respectively. Populations of cicadellids (Fig. 3C), herbivorous hemipterans (Fig. 3D) and coleopterans (Fig. 3E), and dipterans (Fig. 3 F) were more numerous on weedy cotton plants and/or weed foliage during the last half of the sampling dates in 2000. In 2001, however, only the weed foliage supported more cicadellids (Fig. 3C), herbivorous hemipterans (Fig. 3D) and coleopterans (Fig. 3E) than cotton plants in either treatment, and the differences were less pronounced than those observed in 2000. During 2000, thrips were more abundant on weed foliage than on cotton plants in either treatment on the first two sampling dates, and on the third sampling date in 2001 (Fig. 3G). Lepidopteran adults (Fig. 3H) were most abundant on the weed-free cotton plants on the fourth sampling date during 2000, but on the last sampling date, populations were higher on weedy cotton plants and on weed foliage. On the third sampling date of 2000, lepidopterous larvae (Fig. 3I) were more numerous on weedy cotton plants on the third and the last sampling dates in 2000 than on weed-free cotton plants and weed foliage.

Dvac-collected natural enemies in 2000 and 2001 were in the orders Hemiptera, Coleoptera, Hymenoptera, Neuroptera, and Araneae. Repeated measures analyses showed that the treatment had significant effects on the numbers of *Geocoris* spp., *Orius* spp., nabids, neuropterans, formicids, wasps, and spiders in 2000; and on the numbers of *Orius* spp., nabids, coccinellids, neuropterans, formicids, and wasps in 2001 (Table 4). The effects of time were significant on the numbers of *Geocoris* spp., *Orius* spp., nabids, reduviids, neuropterans, wasps, and spiders in 2000; and on numbers of *Orius* spp., nabids, coccinellids, neuropterans, wasps, and spiders in 2001 (Table 4). Interactions between treatment and time effects were detected for numbers of *Geocoris* spp., *Orius* spp., nabids, and reduviids in 2000; and for numbers of nabids in 2001 (Table 4).

During 2000, weedy treatments supported greater numbers of *Geocoris* spp. (Fig. 4A), *Orius* spp. (Fig. 4B), nabids (Fig. 4C), wasps (Fig. 4 F), neuropterans (mostly on weed foliage) (Fig. 4G), and spiders (mostly on cotton foliage) (Fig. 4H) on three or four of the last sampling dates; and coccinellids (Fig. 4D) were more abundant in the weedy treatment on the fourth sampling date. On one to three sampling dates in 2001, the weedy treatment supported more *Orius* spp. (Fig. 4B), nabids (weed foliage only) (Fig. 4C), wasps (weed foliage only) (Fig. 4 F), and neuropterans (Fig. 4G) than the weed-free treatment. Formicids (Fig. 4E) were more numerous in the weed-free treatment on two occasions during 2000 and in 2001.

Ant Colonies. In 2000, there were 0.5 ± 0.3 *S. geminata* colonies per plot in the weedy habitats as compared with 0.3 ± 0.2 in the weed-free habitats, and there were 0.5 ± 0.2 in each of the weedy and weed-free plots during 2001; a significant treatment effect was not detected in either year. Numbers of *Atta* spp. colonies were also low (<0.1 per plot).

Boll Weevil Infestation and Mortality. Mean numbers of squares damaged by boll weevils were not statistically different between weedy and weed-free treatments during 2000 and 2001 (Table 7). Significant position effects on boll weevil mortality between the west (3.7 ± 0.4), middle (3.7 ± 0.5), and east (3.4 ± 0.7) squares on strings were not detected. Similar trends were observed in the weed-free plots. In addition, average mortality in all five squares on the strings in the weedy plots (3.0 ± 0.3) was not significantly different from mortality in the weed-free plots (3.2 ± 0.3). Of the five boll weevil infested squares on each string, ≈50% were killed by heat in the weedy and the weed-free plots, ≈8% were killed by ants in both habitats, ≈2% were killed by disease, and ≈ 40% survived. Treatment effects were not detected for the mortality factors.

Cotton Plant Density and Growth Parameters. Cotton plant densities in the weedy and weed-free plots in the early season of 2000 and 2001 were not statistically different. Late season cotton plant densities in the weedy plots were significantly lower than in the weed-free plots in 2000 (21.5%, $F = 20.41$; df = 1, 10; $P = 0.0011$) and marginally lower in 2001 (11%, $F = 4.44$; df = 1, 10; $P = 0.0614$) (Table 8). There were no treatment differences of numbers of squares per unit length of row in both years, but there were 75% fewer bolls in the weedy plots in 2000 ($F = 43.47$; df = 1, 10; $P = 0.0001$), and weed-free cotton plants were 1.5-fold ($F = 45.80$; df = 1, 10; $P < 0.0001$) and 1.1-fold ($F = 8.82$; df = 1, 10; $P = 0.014$) taller than weedy cotton plants in 2000 and 2001, respectively (Table 9). Lint yield in 2000 was 9.5-fold higher in the weed-free plots than in the weedy plots ($F = 101.95$; df = 1, 10; $P < 0.0001$), and 1.5-fold higher in 2001 ($F = 15.58$; df = 1, 10; $P = 0.0027$).

Discussion

In this study, herbivorous arthropods were considered to be prey although natural enemies can also be consumed by other predatory arthropods (Vinson and

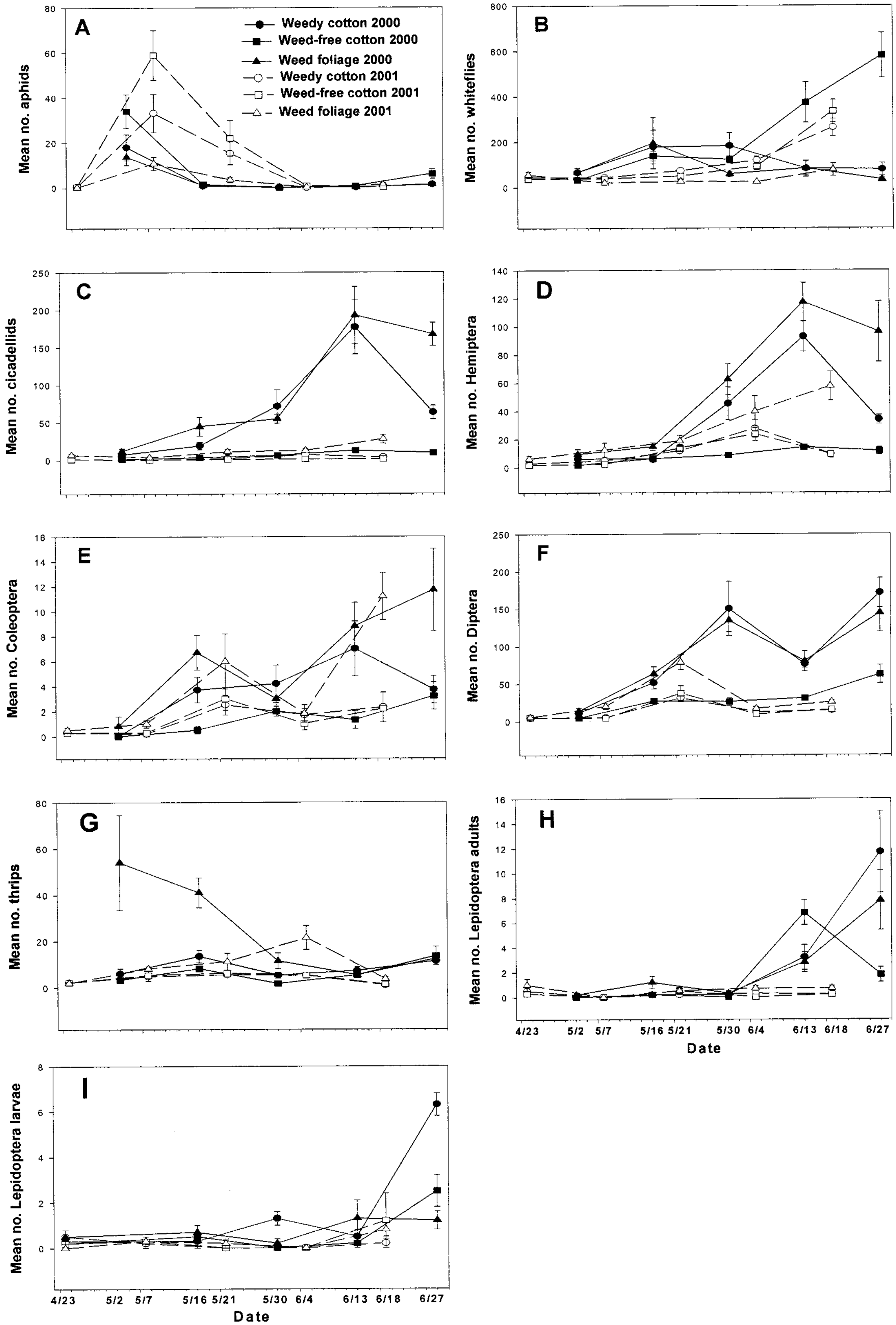

Fig. 3. (A–I) Mean (±SE) numbers of selected prey arthropod groups collected using a dvac machine in weedy and weed-free cotton plots, Hidalgo Co., TX.

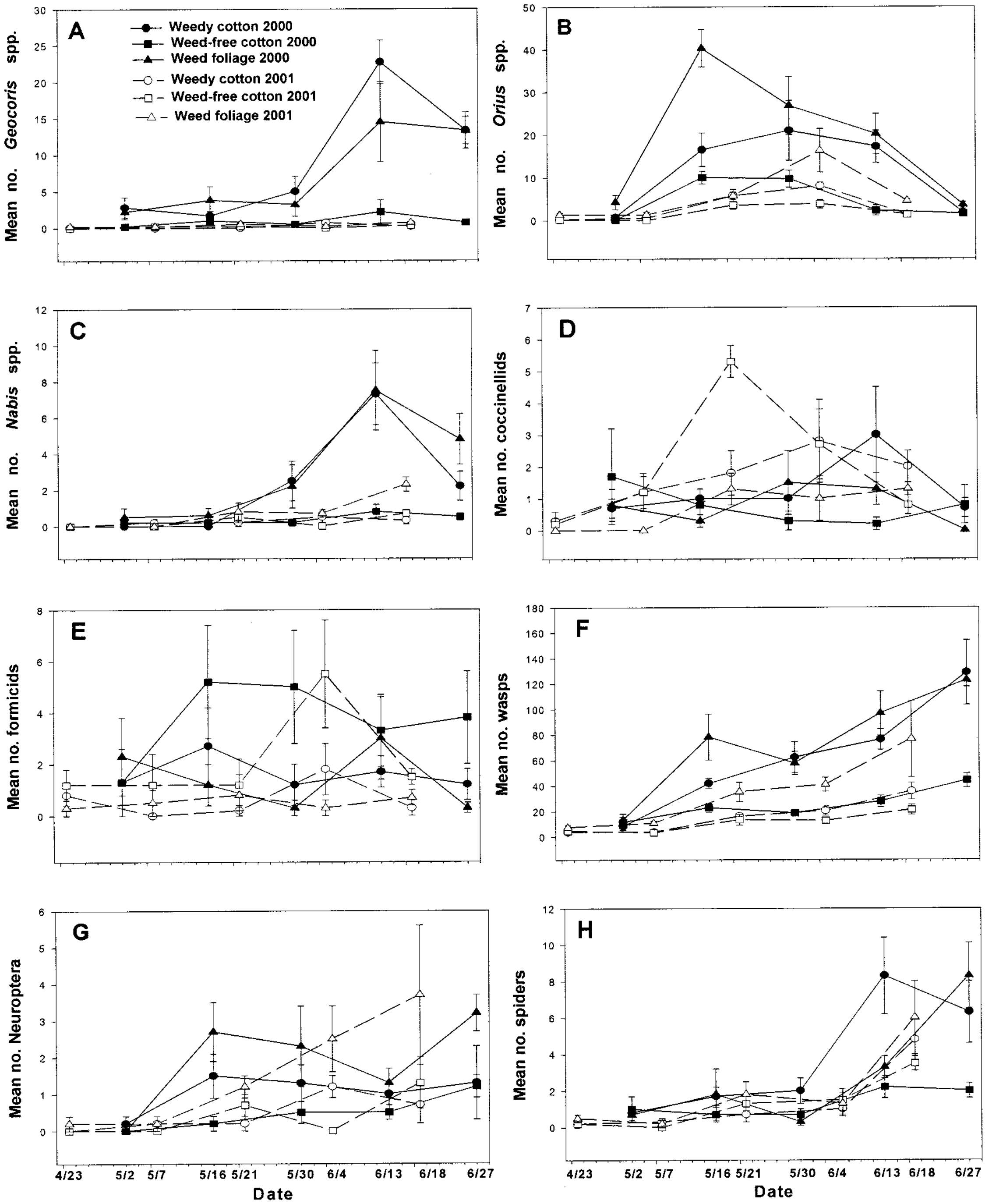

Fig. 4. (A–H) Mean (±SE) numbers of selected natural enemy groups collected using a a dvac machine in weedy and weed-free cotton plots, Hidalgo Co., TX.

Scarborough 1989). Considering both pitfall and dvac data, cicadellids, herbivorous hemipterans and coleopterans, dipterans, thrips, and lepidopteran larvae, and orthopterans generally occurred in the highest numbers in the weedy plots as compared with the weed-free plots, particularly when weed biomass was comparatively high later in the season, and in 2000 when weed biomass was consistently greater compared with 2001. Association of higher numbers of various prey populations with increased weed biomass has been reported in other crops (Altieri et al. 1977, Showler and Reagan 1991) because the additional biomass and diversity of plant species provide more food and refuge. Diversity was also greater in the dvac

Table 7. Mean numbers (±SE) of boll weevil damaged squares out of 50 randomly selected squares per treatment replicate in weedy (W) and weed-free (WF) cotton, Hidalgo County, TX

Treatment	2000		2001	
	22 May	30 May	22 May	30 May
W	10.8 ± 2.0	14.2 ± 2.8	8.3 ± 1.3	7.2 ± 1.6
WF	9.2 ± 3.6	14.7 ± 2.7	7.8 ± 1.3	9.8 ± 1.0
F	0.17	0.02	0.08	2.10
P	0.69	0.90	0.79	0.18

$n = 6$.

samples collected from weed foliage presumably because of the diversity of weed species present. It appears that heavier weed growth favored diversity more than lighter weed growth.

The higher numbers of whiteflies on weed-free cotton than on weed foliage and weedy cotton plants in June 2000, and the higher numbers on cotton plants in the weedy and weed-free plots as compared with weed foliage in 2001, reflect a preference of the silverleaf whiteflies for cotton plants over weeds. The 2000 data suggests that dense weed growth might impede or deter some whiteflies from settling on cotton plants, which has been reported to occur with other insects in different vegetatively diversified cropping systems (Risch 1979, 1980). It is also possible that parasitism of silverleaf whiteflies, reported to be higher on weeds (especially hirsute species) than on cotton (Stansly et al. 1997), contributed to the lower whitefly populations on the weeds. The higher aphid populations on weed-free cotton (on one sampling date in each year) could have occurred for the same reasons that explain the whitefly population trends.

Considering both pitfall and dvac data, natural enemies *Geocoris* spp., *Orius* spp., nabids, carabids, dermapterans, formicids, wasps, neuropterans, and spiders occurred in higher numbers in weedy treatment, especially when weed growth was heavier. This is probably because of greater numbers of herbivorous prey arthropods that accumulated in the weedy treatment, supported by the additional and more diverse plant biomass. Ants and coccinellid beetles, which tend or consume aphids, were more abundant in the weed-free cotton because aphid populations were highest there (Reilly and Sterling 1983, Wells et al. 2001). The increase in coccinellid populations (Figs. 2D and 4D), particularly in 2001, appeared to lag (Price 1975) 2 wk after the aphid population peak (Fig. 3A). In the cases of the other natural enemy groups, population trends were not found to be related to the abundance of any one group of prey arthropods. Whether more abundant in weedy or weed-free habitats, heightened prey availability was associated with abundances of 12 of the 14 predator groups counted in this study. *Collops* beetles and reduviids were the exceptions, but they were collected in low numbers.

Table 8. Mean cotton plant numbers (±SE) per 4-m row in early and late season weedy and weed-free cotton plots in Hidalgo County TX, 2000 and 2001

Treatment	2000		2001	
	20 April	5 July	26 April	11 July
Weedy	44.8 ± 1.9	34.7 ± 1.0b	45.1 ± 1.7	39.9 ± 1.7b
Weed-free	45.0 ± 1.7	44.2 ± 1.9a	45.2 ± 1.5	44.7 ± 1.7a

Means in the same column followed by different letters are different ($P < 0.07$); means not followed by letters are not different ($P > 0.1$); $n = 6$.

Effects of time on eight of the 10 groups of prey arthropods captured by both sampling methods (pitfall and dvac) during both years most likely occurred because the vegetation food resources that the herbivores prefer, whether it was weed-free cotton plants (as in the case of whiteflies) or weed foliage (as in the cases of most of the other herbivore groups), increased with time. The significant effect of time on aphids resulted from the aphid population peaks that occurred early in the season instead of being associated with cotton plant growth. Slosser et al. (1989, 1991) suggested that cotton aphid populations are regulated mostly by interactions between climatic and nutritional factors. Increased duration of light and high temperatures (>72°C) were considered to be primary and secondary order constraints to cotton aphid population growth, respectively. This explains the decline in cotton aphid populations that occurred in late April and early May when temperatures and daylight both increase in the Lower Rio Grande Valley. The early season cotton aphid declines may have been hastened by predators and diseases, but weediness appeared to have no effect on rate of decline The presence of weed foliage did not halt or slow the reduction in cotton aphid populations after they had begun to decline.

Effects of time on 9 of the 14 natural enemy groups during both years in pitfall or dvac collected samples appears to have occurred in response to the increasing quantity of prey items over time. However, correlations between total prey and total natural enemy numbers for the pitfall and dvac samples were not significant because of the large variability in samples (caused to some extent by variability in ant populations), some natural enemy groups were highest in the weedy plots whereas others were highest in the weed-free plots, and some insects were found in relatively large numbers early in the season (e.g., aphids) while other groups of prey increased later in the sampling period (e.g., cicadellids and herbivorous hemipterans). The interaction between treatment and time effects in relation to whitefly numbers reflected the increase in whitefly numbers on the weed-free cotton plants and a slower rate of increase or a decline in whitefly numbers on the weedy cotton plants, and particularly on the weed foliage, over time. Interactions in relation to natural enemy groups were detected in both years only for nabids, presumably because numbers increased with time on the weedy cotton plants and the weed foliage, but populations on the weed-free cotton plants did not markedly change.

Despite a general trend for higher abundances of natural enemies in the weedy treatment, boll weevil oviposition injury to squares was not reduced, and it

Table 9. Mean numbers (±SE) of cotton squares and bolls, plant heights, and lint yields in weedy (W) and weed-free (WF) field plots, Hidalgo County, TX, 2000 and 2001

Year	Treatment	No. squares[a]	No. bolls[b]	Plant heights (cm)[c]	Lint yield kg/ha[d]
2000	W	97.2 ± 6.5	78.8 ± 29.6b	26.1 ± 1.4b	48.8 ± 24.8b
	WF	101.3 ± 10.1	312.5 ± 19.3a	37.8 ± 1.0a	460.7 ± 32.4a
2001	W	139.2 ± 24.1	134.8 ± 14.7	59.5 ± 0.8b	199.7 ± 15.2b
	WF	164.2 ± 7.1	154.7 ± 16.3	66.6 ± 202a	290.8 ± 17.4a

Means followed by different letters within the same column and year are significantly different ($P \leq 0.05$); means not followed by letters are not significantly different.

[a] Per 7.6-m row per plot, $n = 6$, 1 May 2000, 8 May 2001.

[b] Per 7.6-m row per plot, $n = 6$, 19 June 2000, 27 June 2001.

[c] Twenty-five plants per plot, $n = 6$, 15 May 2000, 29 May 2001.

[d] Based on hand picked cotton from two 7.6-m sections of row per plot, $n = 6$, 14 July 2000, 23 July 2001.

is addumed that boll weevil populations were also unaffected. Predatory arthropod populations built to greater levels in weedy plots in late May and June when weed biomass was highest and when most squares had become bolls which are less vulnerable to boll weevil oviposition (Howard 1921). Also, natural enemies indigenous to the United States are not considered to be major causes of mortality to the boll weevil (Jones and Sterling 1979), which is not native to the United States (Hunter and Pierce 1912). Sturm and Sterling (1990) compared mortality factors of the boll weevil in the eastcoastal, midwest, and northcentral regions of Texas. Predation, mostly by the imported fire ant, native to South America (Showler and Reagan 1987), accounted for 58% mortality in the eastcoastal region. Fillman and Sterling (1983) reported that imported fire ant predation on immature boll weevils averaged 84% compared with 0.14% and 6.9% caused by parasitism and desiccation, respectively. Ants were slightly more numerous in weed-free habitats perhaps because of the somewhat higher aphid populations on weed-free cotton (Reilly and Sterling 1983), but without imported fire ant populations, they were not a constraint to boll weevil survival within cotton squares. During the cotton growing season, heat has been identified as a chief cause of mortality to immature boll weevils within abscised squares (Bottrell 1976), and our study showed that heat was the chief cause of immature boll weevil mortality in abscised squares in spite of heightened late season predator populations where weeds grew.

The absence of a treatment effect on the numbers of squares counted during the early season in 2000 and 2001 because boll weevil damage was unaffected by light weed growth and because weed competition with cotton was too low in early May to have caused a decline in cotton plant density and in square production. Later in the season, the fewer bolls in the weedy treatment resulted from lower plant density and vigor caused by weed competition. Lower plant heights were at least partly induced by thigmomorphogenesis (shortening of internodes resulting from physical contact with objects or wind (Jaffe and Forbes 1993)) and shading (Zhao and Oösterhuis 2000) caused by taller weeds (Showler 2002). The lower cotton lint yields in the weedy plots reflected the stand reduction.

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